LONGITUDINAL POLARIZATION OF Λ AND $\bar{\Lambda}$ IN DEEP-INELASTIC SCATTERING AT COMPASS

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Abstract

Production of Λ and $\bar{\Lambda}$ hyperons in deep-inelastic scattering of 160 GeV/c polarized muons is under study in the COMPASS (CERN NA58) experiment. Preliminary results on longitudinal polarization of Λ and $\bar{\Lambda}$ hyperons from the data collected during the 2002 run are presented.

The study of longitudinal polarization of $\Lambda(\bar{\Lambda})$ hyperons in the deep-inelastic scattering (DIS) can provide information on the fundamental properties of the nucleon, such as polarization of strange quarks in the nucleon [1], and offers a possibility to determine the mechanism of spin transfer from a polarized quark to a polarized baryon [2]-[7].

The polarized nucleon intrinsic strangeness model [1] predicts negative longitudinal polarization of Λ hyperons produced in the target fragmentation region [8, 9]. The main assumption of the model is negative polarization of the strange quarks and antiquarks in the nucleon. This assumption was inspired by the results of EMC [10] and subsequent experiments [11]- [13] on inclusive deep-inelastic scattering which gave an indication that the $s\bar{s}$ pairs in the nucleon are negatively polarized with respect to the nucleon spin:

$$\Delta s \equiv \int_0^1 dx[s_\uparrow(x) - s_\downarrow(x) + \bar{s}_\uparrow(x) - \bar{s}_\downarrow(x)] = -0.10 \pm 0.02. \tag{1}$$

Recent analysis [14] of the available world data in framework of the next-to-leading order perturbative QCD including higher twist effects also concludes that $\Delta s = -0.045 \pm 0.007$.

The polarized strangeness model [1] was successfully applied to explain the large violation of the OZI rule in the annihilation of stopped antiprotons and its strong dependence on the spin of the initial state (for review, see [15]). The predictions of the model were confirmed in different processes of proton-proton, antiproton-proton interactions and lepton DIS. Specifically, the negative longitudinal polarization of the Λ hyperons at $x_F < 0$ predicted in [8, 9] was found in the neutrino DIS experiments [16].

However, the question about polarization of the nucleon strange quarks has not been solved yet. Recently, after analysis of the semi-inclusive DIS channels in the LO approximation, the HERMES collaboration found that $\Delta s = 0.028 \pm 0.033 \pm 0.009$ [17], i.e. consistent with zero within the errors (for the discussion of the HERMES result, see [18],[19]).

The measurement of the longitudinal Λ polarization in the current fragmentation region $x_F > 0$ is traditionally related with investigations of spin transfer from quark to

hadron [2]-[6]. This spin transfer depends on the contribution of the spin of the struck quark to the Λ spin. There are different models of the Λ spin structure.

In the naive quark model the spin of Λ is carried by the s quark and the spin transfer from the u and d quarks to Λ is equal to zero. It means that the longitudinal polarization of Λ produced in fragmentation of the u and d quarks is $P_\Lambda \sim 0$.

The authors of [2], using $SU(3)_f$ symmetry and experimental data for the spin-dependent quark distributions in the proton, predict that the contributions of u and d quarks to the Λ spin are negative and substantial, at the level of 20% for each light quark. One might expect that in this model the fragmentation of the dominant u quark will lead to $P_\Lambda = -0.2$.

In the framework of $SU(6)$ based quark-diquark model [6] it is predicted a large and positive polarization of the u and d quarks in the Λ at large Bjorken scaling variable x_{Bj}. Due to this fact the spin transfer to Λ should be as large as $+1$ at $z \sim 0.8 - 0.9$ (here z is fractional hadron energy, $z = E_h/\nu$, $\nu = E - E'$, E and E' are lepton energies in the initial and final state).

However the possibility to study real spin transfer from the quark to baryon at the energies of the current experiments was questioned in [9]. It turns out that even at the COMPASS energy of 160 GeV most of Λ, even in the $x_F > 0$ region, are produced from the diquark fragmentation. It is predicted that in the COMPASS kinematics the longitudinal Λ polarization is either $P_\Lambda = -0.004$ or $P_\Lambda = -0.07$, depending on the fragmentation model.

Moreover, a large part (up to 30-40%) of the Λ, observed in DIS, comes from decays of heavy hyperons, such as Σ^0, $\Sigma(1385)$ and Ξ, significantly changing the pattern of the spin transfer.

More clear situation is with the $\bar{\Lambda}$ production. The contribution of $\bar{\Lambda}$ production from diquark fragmentation is negligible. The background from decays of heavy hyperons is also absent. An interesting feature was observed in the E665 experiment at Fermilab [20]. It was found that in DIS the spin transfer to Λ and $\bar{\Lambda}$ is large and has opposite signs. Though the statistical errors of the measurement were quite large, the statistics comprises only 750 Λ and 650 $\bar{\Lambda}$ events.

The spin transfer to Λ and $\bar{\Lambda}$ for the E665 experimental conditions was calculated in [7]. It is predicted, that under standard assumption that unpolarized strange quark distribution $s(x)$ is the same as $\bar{s}(x)$ for antistrange quarks, the spin transfer to Λ should be practically the same as for $\bar{\Lambda}$. Trying to explain the difference in Λ and $\bar{\Lambda}$ spin transfer, the authors of [7] have introduced by hand some asymmetry in strange-antistrange quark distributions at small x_{Bj}. However, the calculated magnitude of the difference in Λ and $\bar{\Lambda}$ spin transfer was still too small to explain the data [20].

We have studied Λ and $\bar{\Lambda}$ production by polarized μ^+ of 160 GeV/c on a polarized ^{6}LiD target of the COMPASS spectrometer constructed in the framework of CERN experiment NA58. A detailed description of the COMPASS experimental setup is given elsewhere [21] and only the most relevant elements for the present analysis will be given below.

The beam polarization is $P_b = -0.76 \pm 0.04$. The polarized ^{6}LiD target consists of two oppositively polarized cells, 60 cm long. The target polarization is about 50%. For this analysis the data are averaged over the target polarization.

We have used data collected during the 2002 run. The analysis comprises about $1.6 \cdot 10^7$ DIS events with $Q^2 > 1$ $(\mathrm{GeV}/c)^2$.

The V^0 events ($V^0 \equiv \Lambda$, $\bar{\Lambda}$ and K^0_S) were selected by requiring the incoming and outgoing muon tracks together with at least two hadron tracks forming the secondary vertex. The primary vertex should be inside the target. The secondary vertex must be downstream the both target cells. The angle between the vector of V^0 momentum and the vector between primary and V^0 vertices should be $\theta_{col} < 0.01$ rad. Cut on transverse momentum of the decay products with respect to the direction of V^0 particle, $p_t > 23$ MeV/c was applied to reject e^+e^- pairs from the γ conversion seen as the band at the bottom of the Armenteros plot shown in Fig.1.

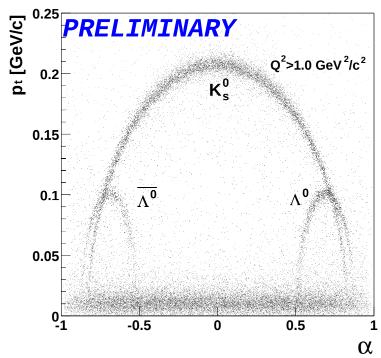

Figure 1: The Armenteros plot: p_t is the transverse momentum of the V^0 decay products with respect to the direction of V^0 momentum, $\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$, where p_L is the longitudinal momentum of the V^0 decay particle.

The typical elliptical bands from the K^0_S, Λ and $\bar{\Lambda}$ decays are seen in Fig. 1. Both Λ and $\bar{\Lambda}$ signals stand out clearly. The large number of produced $\bar{\Lambda}$ is a specific feature of the COMPASS experiment.

The DIS cuts on $Q^2 > 1$ $(\mathrm{GeV}/c)^2$ and $0.2 < y < 0.8$ have been used. Here $y = \nu/E$ is the fraction of the lepton energy carried out by the virtual photon.

To analyse V^0 events, the so called bin-by-bin method was used. All angular distributions have been divided in some bins. In each angular bin the invariant mass distribution of positive and negative particles is constructed assuming $\pi^+\pi^-$, $p\pi^-$ or $\bar{p}\pi^+$ hypothesis. The peak of the corresponding V^0 particle is fitted and the number of the V^0 in this peak is obtained. This number determines a point in the corresponding bin of the angular distribution. This procedure allows to construct practically background-free angular distributions. The total data sample contains about 9000 Λ and 5000 $\bar{\Lambda}$.

The x_F and Q^2 experimental distributions (crosses) of Λ, $\bar{\Lambda}$ and K^0_S are compared with the Monte-Carlo simulated ones (hatched histograms) in Fig. 2. One can see that we are able to access mainly current fragmentation region. The averaged value of x_F is $< x_F >= 0.20$, whereas for the Bjorken scaling variable it is $< x_{Bj} >= 0.02$. The mean Λ momentum is 17 GeV/c, while decay pion momentum is 3 GeV/c. The agreement between the experimental data and the Monte-Carlo simulations is reasonable.

The angular distribution of the decay particles in the V^0 rest frame is

$$w(\theta) = \frac{dN}{d\cos\theta} = \frac{N_{tot}}{2}(1 + \alpha P \cos\theta), \qquad (2)$$

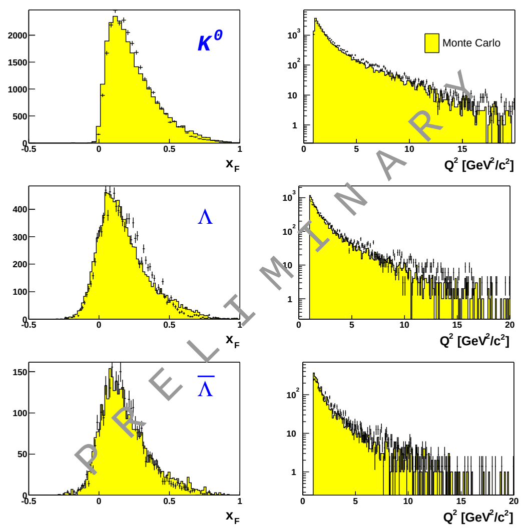

Figure 2: The x_F (left column) and Q^2 (right column) distributions for K^0_S (upper row), Λ (middle row) and $\bar{\Lambda}$ (lower row). The experimental data points are shown together with results of Monte-Carlo simulations (histograms).

where N_{tot} is the total number of events, $\alpha = +(-)0.642 \pm 0.013$ is $\Lambda(\bar{\Lambda})$ decay parameter, P is the projection of the polarization vector on the direction of the virtual photon in the V^0 rest frame, θ is the angle between the direction of the decay proton for Λ (antiproton - for $\bar{\Lambda}$, positive π - for K^0) and the direction of the virtual photon in the V^0 rest frame.

Fig. 3 shows the measured angular distributions for all events of the K^0_s, Λ and $\bar{\Lambda}$ decays, corrected for the acceptance. The acceptance was determined by the Monte Carlo simulation of unpolarized $\Lambda(\bar{\Lambda})$ decays.

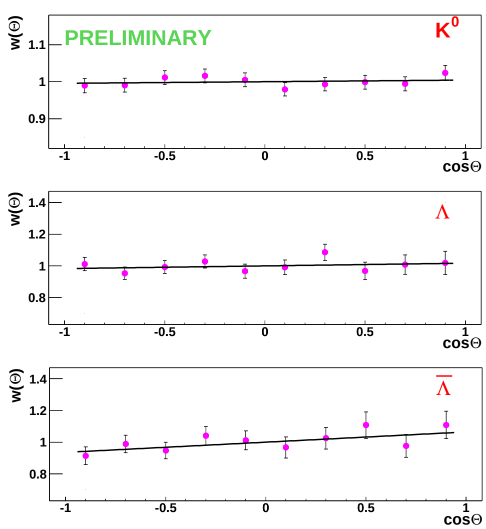

Figure 3: The angular distributions for K^0_S, Λ and $\bar{\Lambda}$ for all events.

One could see that the angular distribution for K^0_S decays is flat, as expected. The value of the longitudinal polarization is $P_K = 0.007 \pm 0.017$. The angular distribution for Λ decays for all events, i.e. the averaged other whole x_F interval, is also flat. The value

of the longitudinal polarization is $P_\Lambda = 0.03 \pm 0.04(stat) \pm 0.04(syst)$. It indicates on small polarization of Λ in DIS processes. The same trend was observed by the HERMES collaboration [22]. The angular distribution of the $\bar{\Lambda}$ events, averaged over x_F, exhibits some negative polarization $P_{\bar{\Lambda}} = -0.11 \pm 0.06(stat) \pm 0.04(syst)$.

Comparison of the spin transfer to Λ and $\bar{\Lambda}$ hyperons measured in different DIS experiments is shown in Fig. 4. The spin transfer S determines which part of the beam polarization P_b is transferred to the hyperon polarization P. It is defined as
$P = S \cdot P_b \cdot D(y)$, where $D(y)$ is the virtual photon depolarization factor.

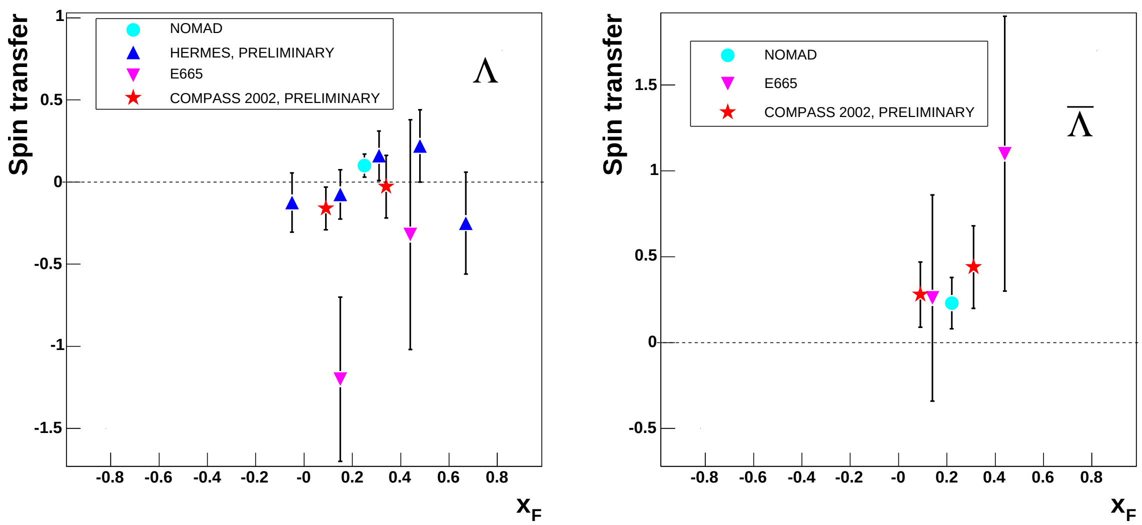

Figure 4: Comparison of the spin transfer to Λ (left) and $\bar{\Lambda}$ (right) hyperons measured in different DIS experiments.

One can see that there is a reasonable agreement between the COMPASS and world data. There is an indication that the spin transfer to $\bar{\Lambda}$ is non-zero and might be different from Λ case. However, for the COMPASS data only statistical errors are shown. Work to determine the systematic errors is going on.

The results from our 2002 data demonstrate a good potential of COMPASS to measure Λ and $\bar{\Lambda}$ polarizations in DIS. The data samples collected in 2003 and 2004 will significantly increase the statistics.

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